Thesis Summary

Particle Number Asymmetry Generation in the Universe
(宇宙の粒子数非対称性の生成)

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What still not yet fully understood within the standard model of particle physics is the origin of baryon asymmetry of the universe (BAU). To address this issue, many different models and mechanisms have been proposed. The mechanisms discussed in literatures satisfy the three Sakharov's conditions: (1) baryon number violation, (2) charge and charge-parity violations, (3) a departure from the thermal equilibrium. Recently, the method with quantum field theory for the calculation of BAU has been also developed.

In this thesis, we developed a new mechanism for generating particle number asymmetry (PNA). This mechanism is realized with the specific model Lagrangian which we have proposed. The model includes a complex scalar. The PNA is associated with U(1) charge of the complex scalar. In addition, we introduce a neutral scalar which interacts with the complex scalar. The U(1) charge is not conserved due to particle number violating interaction. As another source of particle number violation, the U(1) symmetry breaking mass term for the complex scalar is introduced. In our model, the condensation of the neutral scalar field has a time-dependent expectation value. Since the complex scalar field carries U(1) charge, the interactions with the condensation generate PNA. The initial value for the condensation is nonzero. To obtain the time evolution of the PNA, we use two-particle-irreducible formalism combined with density operator formulation of quantum field theory. The initial conditions of the quantum fields are specified with the density operator and it depends on the temperature of the universe at the initial time. To include the effect of the time dependence of the scale factor, we expand it around at the initial time and keep the first derivative of the scale factor.

We found that the interaction coupling and the mass squared difference caused by the U(1) breaking mass term give rise to nonvanishing PNA. In addition, the non-vanishing initial value of the condensation is necessary. Another important finding is that the effect of the expansion of the universe on PNA is divided into three types. Besides the constant scale factor which is the zeroth order of Hubble parameter, there are three types contributions which are the first order terms of the

expansion rate. Those are the effect of dilution of the PNA, freezing interaction effect and the redshift of the particle energy.

We numerically studied the time evolution of the PNA and investigated its dependence on the temperature, the angular frequency and the expansion rate of the universe. We also investigated the parameter B dependence on PNA which corresponds to the mass spectrum of the model. In the simulation, we found two typical cases. One of which corresponds to the longer period and the other corresponds to the shorter period. In our model, even for the longer period case, the oscillation period is shorter than the Hubble time which implies the third Sakharov's condition is not satisfied. In this respect, due to the finite life time of the condensation, we expect that the interaction between the condensation and complex scalars will vanish and eventually the oscillation of the PNA may terminate. The relation between the PNA and BAU should be also studied. These issues will be completed in future research.